

USING GIS MODELLING TO ASSESS ACCESSIBILITY IMPROVEMENTS AND ITS POTENTIAL INDIRECT EFFECTS ON THE ENVIRONMENT DUE TO TRANSPORT INFRASTRUCTURE PLANS DEVELOPMENT

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ABSTRACT

The Strategic Environmental Assessment Directive (2001/42/EU) establishes that the Environmental Report must include the identification and evaluation of the likely significant effects on the environment of implementing the Plan or Programme due to be studied. Transport Plans usually generate accessibility improvements or facilitate access between two given points on the territory. One indirect impact that this action implies is a likely pressure increase in those areas where a great improvement in their accessibility is gained, mainly through high speed motorways. This new pressure comes from the sudden and sometimes messy attraction of potential activities that could vary from industrial, agriculture or services sectors, an increase of tourism or recreational activities..., and the appearance or intensification of residential demand, including secondary or recreational houses.

The Transport Research Centre of the polytechnic University of Madrid (TRANSyT) has coordinated a research project, financed by the Ministry of Public Works, which its main objective has led to obtain, develop and analyse interdisciplinary information to assist on a better infrastructure planning process. In the framework of this project, a methodology has been proposed to assess potential indirect impacts on the environment caused by transport infrastructure developing in previously semi-isolated areas. The process involves the computation of accessibility indices based on travel time estimations on road and railway networks in conjunction with its combination with Natural Quality cartography, also developed through an ad-hoc methodology.

Two analyses have been performed using Iberian transport networks, both for 1992 and 2004, which were later crossed with the Natural Quality cartography obtained in a previous stage of the project. In the light of these analyses, the performance capacity of the Geographic Information Systems is proven and highlighted, concluding that this methodology is suitable for planning improvement.

PAPER

OBJECTIVES

The objective is to know the indirect impact provoked by an increase of the accessibility in the Spanish peninsular territory on the environment. The increase in the accessibility is obtained through the improvement of the existing infrastructures of transport and through the construction of new other ones in those areas less endowed with them. It is intended to develop a methodology that allows the evaluation of this impact using the tools provided by a G.I.S.

METHODOLOGY

Accessibility model

The calculation of the improvement in the accessibility in the period 1992-2004 has been developed by a team directed Gutiérrez Puebla, J. as part of the mentioned project of investigation.

The developed methodology has been applied for the period 1992-2004, and the different results that are exposed in this paper correspond to this period. At present the methodology is being applied by TRANSyT for the 2004-2020 period, within the framework of a project financed by the Ministry of Science and Technology, and therefore further modifications of the initial methodology would be also explained as consequence of the continuity of the study.

Theoretical basis

The accessibility has measured up in terms of efficiency of the net in the connections of every node to the different centres of activity. To neutralize the effect of the geographical location of the nodes, and to highlight the effect of the infrastructure, the usual notion of distance (length, time, cost) is replaced by one that expresses the facility of access in relative terms. The indicator of efficiency of the net relates to the real times of access in contrast with the ideal ones (maximum speed allowed and a straight-line route) to obtain this effect (Gutiérrez Puebla, Monzón and Piñero, 1992; MOPTMA, 1993) applying the following form:

$$A_i = \frac{\sum_{j=1}^n \left(\frac{I_{ij} * w_{ij}}{II_{ij}} \right)}{\sum_{j=1}^n w_{ij}} \quad (1)$$

Where

- A_i ; it indicates the efficiency of the net in the connections of the node i with regard to the considered centres of activity.
- I_{ij} = impedance; real time of displacement taking the shortest path (minutes).
- II_{ij} ; it is the ideal time of trip between the node of origin and the destination centre of economic activity: the time that would be obtained in straight line across a hypothetical highway or line of high speed.
- w_{ij} ; it is the weighing for this relation between i and j (in this case the quotient between the population in destiny and the time of trip between i and j).

Methodology

In a Geographical Information System (ARC/INFO), which combines cartographic and alphanumeric information, both motorway and railroad network have been represented, covering the whole territory of the peninsular Spain. Both are updated to 31 in December, 2003.

The procedure has started with the ESRI muniview dataset for the year 2002 as the base map at the scale of 1:2000000. The reasons under the decision of using this scale are, firstly, that the intention was to analyse the effects on a wide scale of the peninsular territory and, secondly the fact that other models developed at different stages, for instance demand model, were developed at this scale.

The used format has been ArcInfo's coverage, because it allows an analysis of networks built by arcs and nodes. Information relating to distance and speed of trip is incorporated in the arcs, while nodes retain information related to population of the locality and penalties of time owed to transfers caused by the effect of the infrastructure or due to changes of rail track widening.

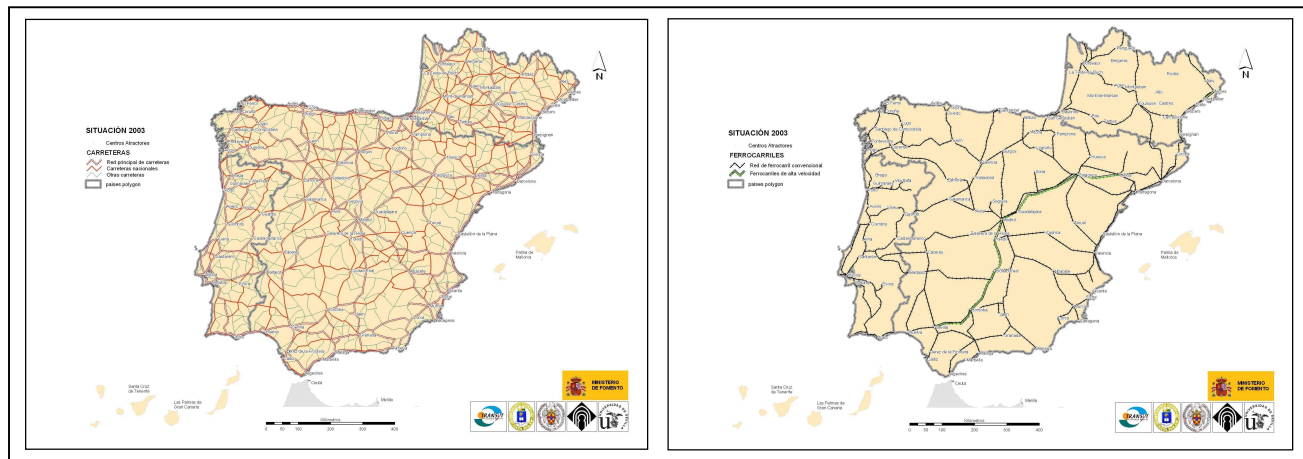


Figure 1: Motorway and Railway Networks

Due to the recently approved Strategic Plan of Infrastructures and Transport (PEIT) in Spain, it has been necessary to update and extend current networks with the actions and new infrastructure development foreseen on the mentioned Plan in order to extent the study and analyse accessibility improvements due to take place before 2020. The procedure has been the following:

1. Foreseen networks for 2020 (according to the PEIT) have been georeferencing, consisting in a flat transformation based on a sufficient sample of control points. The mistake estimated in the process across the statistician RMS (root mean square) was 504, 989 and 1.050 m for the maps of Spain, Portugal and France. This supposes a precision loss, assuming error binormality according to Central Theorem of the Limit, of 1.788 m. This loss of precision only affect on the new sections, not to the already existing ones (that suffer only a thematic, not spatial update); therefore, bearing in mind the limited level of detail on the definition of the new projects (at this decision level, one can not expect a good definition of proposals, which should be improved at project level), this loss of precision is acceptable. The estimated final precision (assuming independence and binormality of the mistakes) is close to 2.000 m at 95 %, which match to a final scale of 1:2.000.000 according to the current European standards.
2. To edit the networks wherever it is necessary with help of the available edition tools in ArcTools/ArcEdit, which allows arcs and nodes modification.

Once all the information have been incorporated to the network arcs and nodes, the accessibility calculation for all the cities (nodes) that have been considered as centres of economic activity is proceeded. Thus, the order INTERACTION of ArcPlot has been used, which computes the spatial interactions between origin and destination pairs defined on point or polygon features or between a set of nodes and centers, obtaining a new table.

After calculating the accessibility of the nodes considered as attraction centers, applying the expression 1, results are interpolated to the whole peninsular territory using a linear algorithm, Inverse Distance Weighted (IDW), with the help of the geostatistical tools of ArcMap. (IDW interpolation explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW will use the measured values surrounding the prediction location. Those measured values closest to the prediction location will have more influence on the predicted value than those farther away. Thus, IDW assumes that each measured point has a local influence that diminishes with distance. It weights the points closer to the prediction location greater than those farther away, hence the name inverse distance weighted.) and a resolution of 100 meters, which correspond to the decided scale of 1:350.000. Results are shown below in figures 2 and 3.

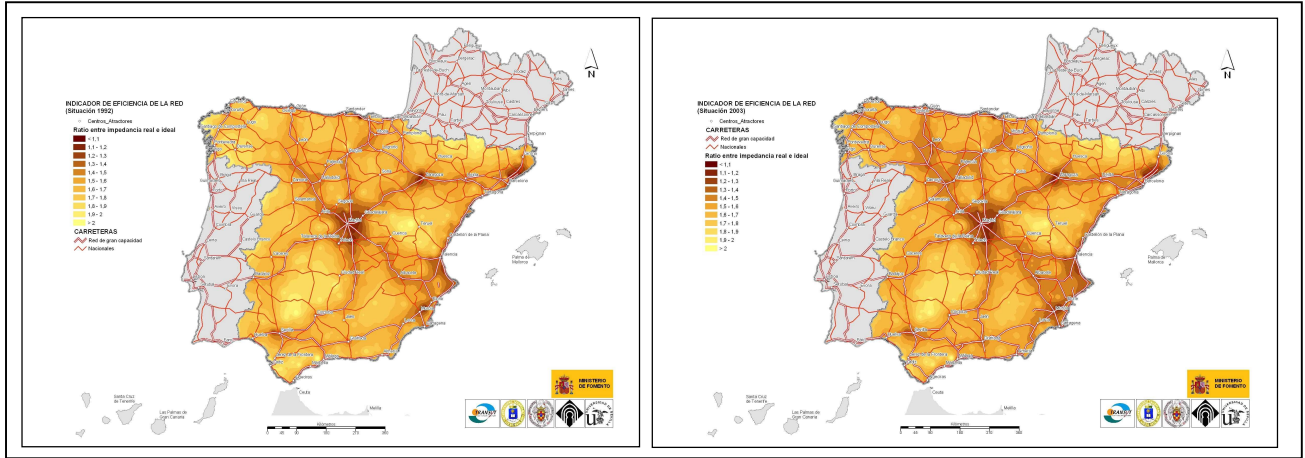


Figure 2: Accessibility. Motorway Network, 1992 and 2004

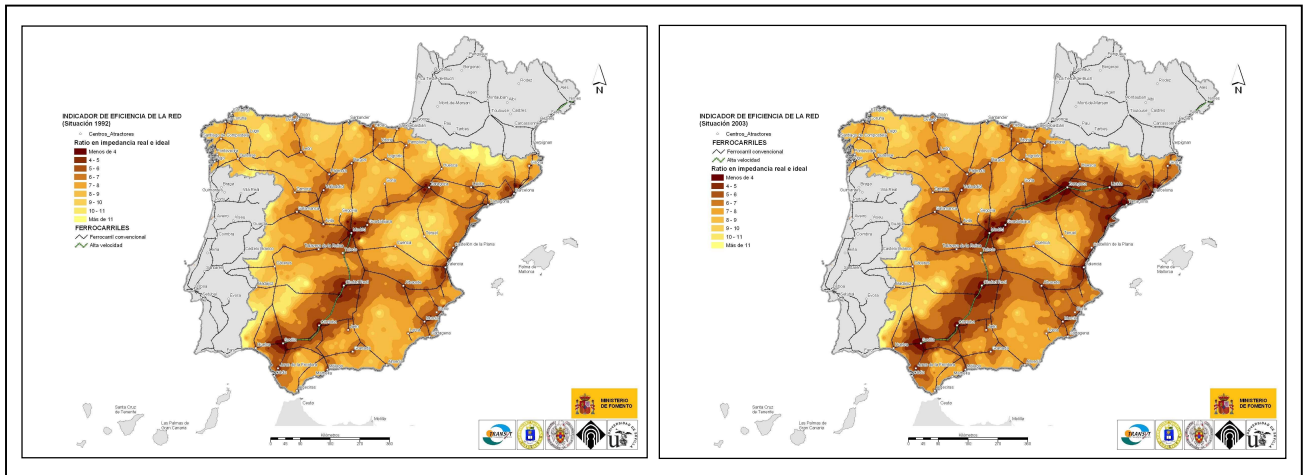


Figure 3: Accessibility. Rail Network, 1992 and 2004

ArcInfo has a command that provides a measure of the accessibility. The command is named Accessibility, which uses the following expression:

$$P_i = \sum_{j=1}^n \frac{W_j}{d_{ij}^\beta} \quad (2)$$

where

- P_i ; accessibility at point i .
- W_j ; attractiveness of location j .
- d_{ij} ; distance between location i and j .
- β ; exponent for distance decay.

However, in order to calculate the potential induced impact, the previous mentioned index (expression 1) was used, since it describes more accurately the improved accessibility to the territory as a whole, that is, considering the multiplicity of purposes that it is intended to evaluate: industrial, agricultural access to houses, tourism and recreation, etc.

EVALUATION OF THE INDIRECT POTENTIAL IMPACT

Environmental Quality Model

The indirect potential impact (López, E. Sánchez, A. (2004) Conflicto entre accesibilidad y preservación del medio: el caso de Pirineos, II Congreso Internacional de Ingeniería Civil y Medio Ambiente. Santiago de Compostela) caused by an accessibility increase has been measured by integrating the map of Natural Quality (Mancebo, S. García-Montero, Luis G. and others), developed in a previous stage of the project, and the accessibility maps (index of efficiency).

The Natural Quality map integrates the most relevant aspects of the environment, as it has been obtained by the combination of 12 environmental variables, which were valued objectively and independently according to the available information and inherent main characteristics, either using GIS models or through expert panels.

Considered variables in Natural Quality Map
Landuse Corine Land Cover Naturalness
Habitat Naturalness
Landscape Quality
Soils Quality
Vegetation cover Valuation
Forest cover (30 % and > 5 m) Valuation
Habitat Map territorial unit Singularity
Landuse Corine Land Cover territorial unit Singularity
Landscape Map Singularity
Soil Map Singularity
Forest fragmentation
Habitat fragmentation

Figure 4: Considered variables in Natural Quality Map

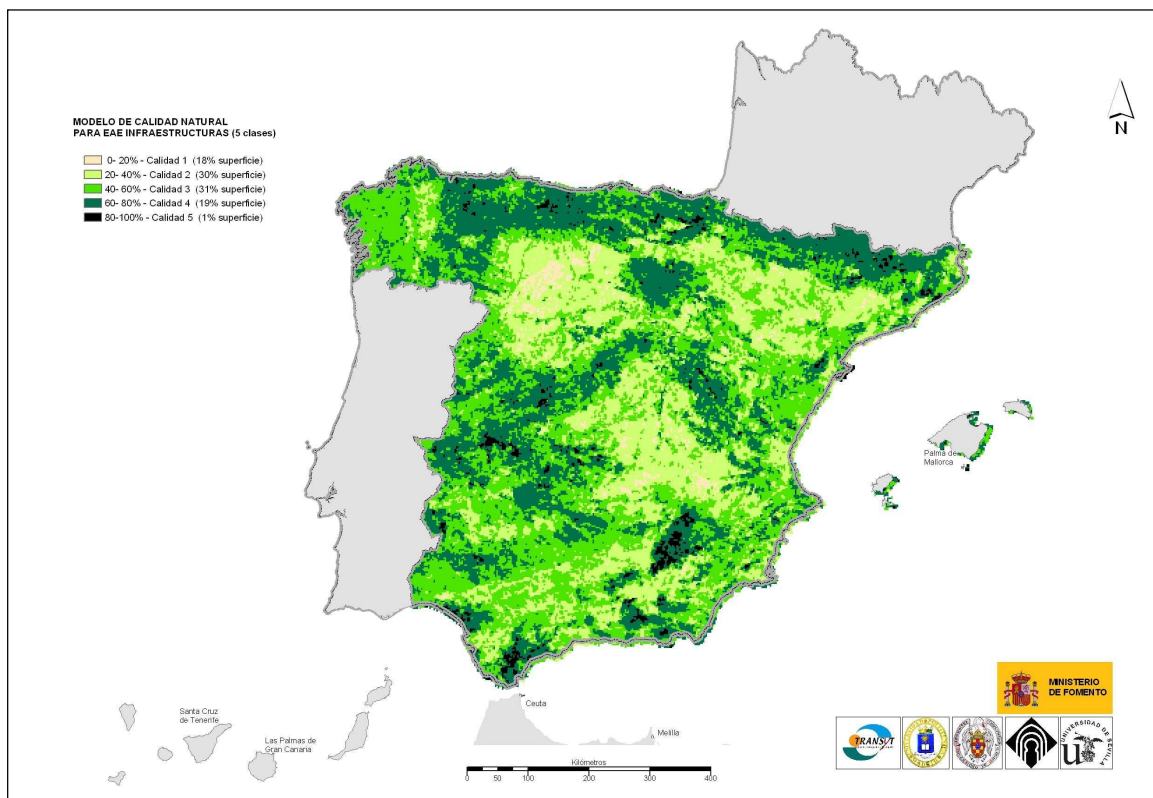


Figure 5: Natural Quality Map

Accessibility Model Normalization

The process adopted in the present study has been the following:

- The starting point is the accessibility to the network nodes, considering roads and railways separately, in 1992, 2004 and their difference.
- Their projection is transformed from the original one (UTM spindle 30 N datum ED-50) to match the Natural Quality map (LAEA European definition ETRS-89 datum)

Integration of Natural Quality and Accessibility maps

The combination of the accessibility map for 1992 and 2004 with the Natural Quality map inform us about the territory potentially affected by activities derived from the increased easiness of access. The methodology used for the evaluation has consisted in computing the accessibility difference between both scenarios, and combining the result with the environmental quality.

The maps are then integrated using the GIS command COMBINES, which combines multiple grids on to cell-by-cell basis within the analysis window, such that to unique output value is assigned to each unique combination of input values. Therefore, a new map is generated through the combination of all possible values or classes from both maps, and total surface for each combination is calculated.

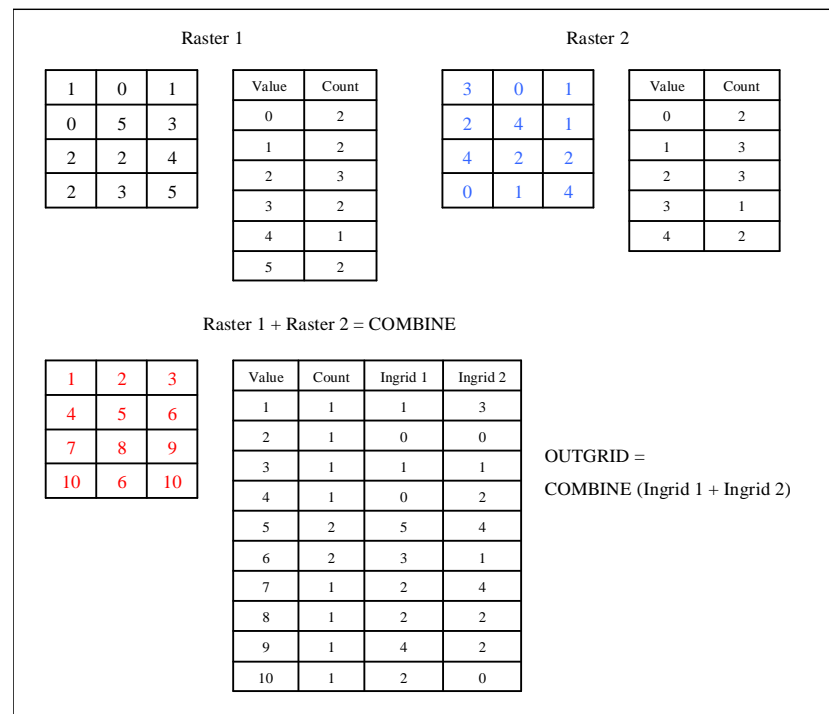


Figure 5: ArcInfo COMBINE command operation

This method allows graphic visualization of those areas where accessibility has been modified, and its relation with the environmental quality:

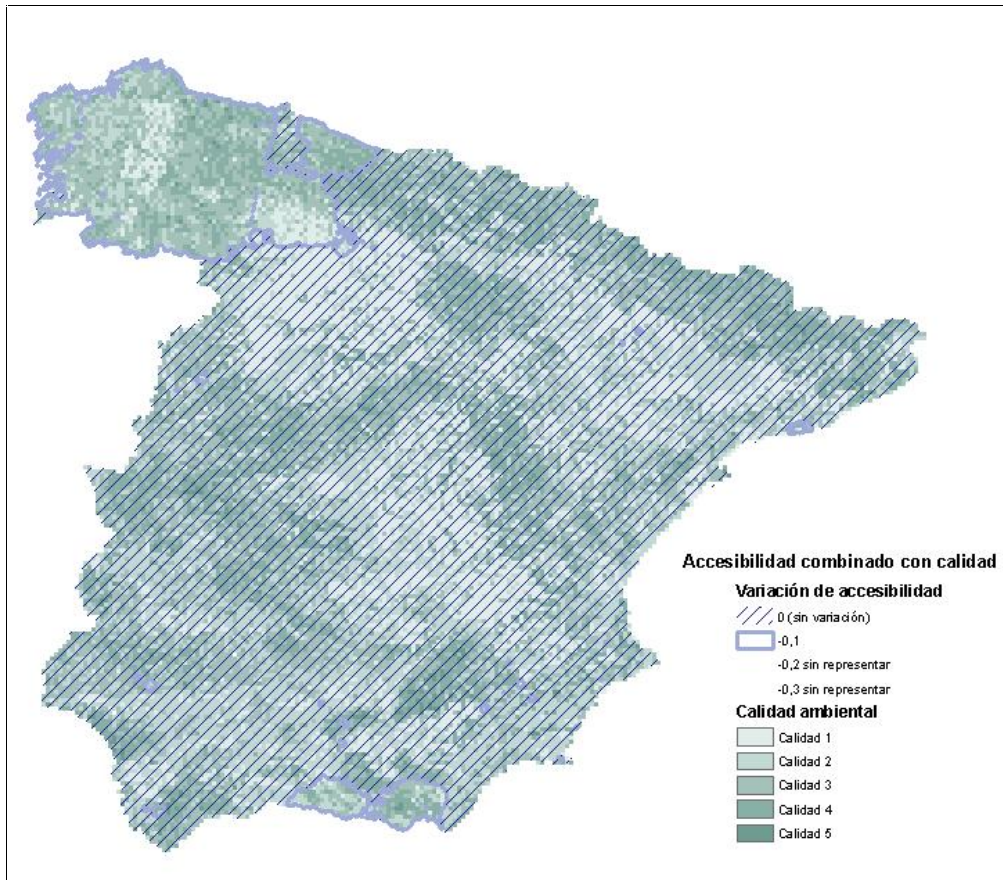


Figure 6: Natural Quality Map and differences in Accessibility between scenarios 1992 and 2004 due to road network improvements.

The GIS command SUMARIZE provides a summary of the surfaces of all the combinations obtained through maps integration, which is useful for its later mathematical and graphic treatment.

By summarizing the data in a table, various summary statistics can be derived—including the count, average, minimum, and maximum value—and get exactly the pursued information. ArcMap creates a new table containing the summary statistics.

RESULTS

Analyzing the report of surfaces, the following table (surfaces in km²) is obtained:

Quality	Accessibility variation				Total
	0	-0,1	-0,2	-0,3	
1	85.800	5.273	0	0	91.073
2	133.555	14.137	59	0	147.751
3	127.009	26.488	81	0	153.578
4	81.581	14.222	9	0	95.812
5	4.980	455	1	0	5.437
Total	432.925	60.575	151	0	493.651

Figure 7: Affected surface by Natural Quality class and accessibility variation

And, calculating surface distribution by percentages with regard to the total for each of the Natural Quality classes:

Quality	Accessibility variation				Total
	0	-0,1	-0,2	-0,3	
1	94%	6%	0%	0%	18%
2	90%	10%	0%	0%	30%
3	83%	17%	0%	0%	31%
4	85%	15%	0%	0%	19%
5	92%	8%	0%	0%	1%
Total	88%	12%	0%	0%	100%

Figure 8: Percentage of affected surface by Natural Quality class and accessibility variation.

The methodology that has been followed in order to analyse differences shows clearly the affected surfaces but, on the other hand, it does not allow the generation of indicators that could also be of great utility. Thus, accessibility maps for 1992 and 2004 shall be “combined” separately with the Natural Quality, in order to get potentially affected territory.

PROPOSED METHODOLOGICAL SCHEME

1. GIS digitalization and edition of the element causing the effect due to induced an indirect impact (Digitalization, Edition,...). (for instance, Transport Networks)
2. Calculation of the variable causing the indirect effect (Modelling, Interpolation,...). (p.e. Improvement of accessibility)
3. Identification of the element that suffers the impact. (p.e. Natural Quality)
4. Integration of both models (Combine in raster, Union in vectorial,...)
5. Data gathering for further analysis (Sumarize,...)

DISCUSSION OF THE ANALYSIS

The evaluation of indirect potential impacts on the environment due to a new Plan or Program is undoubtedly ambitious and indeed very complex. The developed methodology that has been applied in this epigraph must be considered as a first approach, although it has been intended to develop simple but objective and well suited evaluation.

GIS is a great tool to develop models to evaluate territorial variables. We can create maps using its tools, interpolating, digitalizing,...and raster format allows combine numerous variables easily.

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Mancebo, S.; García-Montero, L. G.; Otero, I.; Casermeiro, M. A.; Espluga, A. P. y Navarra, M., Authors of Natural Quality Map.

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BIOGRAPHY

Emilio Ortega, Forestry Engineer, he has researched in 3 projects including Evaluación de los efectos del Plan de infraestructuras 2000-2007 sobre la movilidad, el territorio y la socioeconomía, en el contexto de la unión europea ampliada Analysis of mobility, territory and socioeconomic effects caused by the infrastructure plan of 2000-2007. He has published 2 posters and brief communications in congresses, being related to transport planning focusing on environmental issues and landscape ecology, and he teaches GIS on graduate and postgraduate levels and researches on environmental and physical assessment and planning.